The Evolution of HAZARD, the Fire Hazard Assessment Methodology

Walter W. Jones
Fire Modeling and Applications Group, Building and Fire Research Laboratory, National Institute of Standards and Technology, Gaithersburg, Maryland

Abstract

The United States alone spends about $700 billion a year on new and renovated construction. About 20% of this money assures safety from unwanted fires, and this portion includes the cost of insurance to families and businesses. This enormous cost could be reduced by introducing fire safe products to the building and transportation industries, both in the United States and abroad, and by introducing advanced detectors, suppression systems, and firefighting equipment to the fire protection industry. In order to show that these products and mechanisms are safe to use, industries need performance measures. Performance-based fire standards are currently being developed to augment prescriptive standards around the world.

Performance-based standards are intended to provide flexibility in maintaining accepted fire safety levels among competitive products, while ensuring life safety and reducing property loss. At the same time, performance-based requirements should reduce design and construction costs, as well as the cost of maintenance and liability coverage. In order to derive these benefits, evaluation tools are needed. One such tool, HAZARD I, helps users understand the consequences of unwanted fires by making the results of recent fire research available to them. Improvements to the program will include increased applicability, improved usability, the ability to address additional building features, and more accurate treatment of fire behavior and its effects on people and their actions. Many of the improvements made already in the software documentation are based on the experience of fire protection engineers and others who have used the program. User input, combined with other planned program improvements, constitute the first step in the overall goal of a complete Fire Hazard assessment methodology.

Introduction

The United States alone spends about $700 billion a year on new and renovated construction. About 20% of this money assures safety from unwanted fires, and this portion includes the cost of insurance to families and businesses. This enormous cost could be reduced by introducing fire safe products to the building and transportation industries, both in the United States and abroad, and by introducing advanced detectors, suppression systems, and firefighting equipment to the fire protection industry. In order to show that these products and mechanisms are safe to use, industries need performance measures. Performance-based fire standards are currently being developed to augment prescriptive standards around the world.

Key words: fire modeling, building design, fire growth, smoke movement

Performance-based standards are intended to provide flexibility in maintaining accepted fire safety levels among competitive products, while ensuring life safety and reducing property loss. At the same time, performance-based requirements should reduce design and construction costs, as well as the cost of maintenance and liability coverage. In order to derive these benefits, evaluation tools are needed.

When designing performance-based standards, it is important to include all stakeholders in the decision-making process, from local officials, to the model code organizations, to the professional societies, to those who develop the methodologies. It is important to demonstrate to these groups that performance-based standards will provide a higher level of safety as well as reducing barriers to the introduction of new technologies and products. The Fire Hazard assessment methodology is the first component in a performance-evaluation system.

The Hazard methodology[1] is a tool to help users understand the consequences of unwanted fires. Hazard methodology is intended to make fire research available, so that users can apply it. At present, the methodology prototype is known as HAZARD I.

The scope of this prototype, its database, and its sample cases are focused on single-family residential occupancies. Its primary limitation is the rule set used in the egress model, as opposed to the inherent limitations of the fire model. Improvements will include making the current procedure more applicable, improving usability, upgrading the program's ability to address additional building features, and presenting a more accurate treatment of the fire itself and the effects of the fire on people and their actions. As with codes and standards, the choice of what is to be included at each step of this improvement process is based on a consensus of what the users believe is most important. The goal is to make fundamental research available in a more timely way, and, to some extent, to alleviate the tedium associated with applying a multiplicity of formulae to solve a problem. This is particularly important within a field as complex as fire research.

The methodology consists of a set of procedures combining expert judgment and calculations for estimating the consequences of a specified fire. These procedures involve four steps: defining the context, defining the scenario, calculating the hazard, and evaluating the consequences.

Steps defining the context, defining the scenario, and evaluating the consequences are largely judgmental and depend on the user's expertise. Calculating the hazard, which involves extensive use of HAZARD I software, requires considerable expertise in fire safety practice. The core of HAZARD I is a sequence of procedures implemented in computer software to calculate the development of hazardous conditions over time, to calculate the time needed by building occupants to escape under those conditions, and to estimate the resulting loss of life based on assumed occupant behavior and tenability criteria. These calculations are performed for specified buildings and fire scenarios of concern.

The centerpiece of HAZARD I is a zone model of fire growth and smoke transport. The Hazard methodology surrounds this with models of egress and tenability, auxiliary computer codes, databases, and tables to make the program usable. The software is evolving in several directions. These include increasing the scope of the physical phenomena modeled, adding behavior rules, and supplying more flexible computing capabilities.

The first release of the methodology was HAZARD I, version 1.0, in the Summer of 1989. HAZARD I version 1.1 was released in the spring of 1992. Version 1.2 was published in the spring of 1994. Many improvements have been made in the software documentation, based on the experience of fire protection engineers and others users.

The lessons learned from users of HAZARD I, in addition to other planned improvements, have brought about a true Fire Hazard Assessment methodology. It is difficult to overestimate the impact that HAZARD is having on the fire protection community. Its results are accepted in liability adjudication, criminal proceedings, building code exceptions, and so on.

History

Over the past decade, the fire program of the Building and Fire Research Laboratory (formerly the Center for Fire Research) has developed computer-based models as predictive tools for estimating the effects of fire on a building and those inside it. In the beginning, three models were developed. These were FAST, FIRST, and ASET. Then, in 1985, development of the Consolidate Computer Fire Model (CCFM) was begun. CCFM was originally intended to be a benchmark fire code, with all algorithms of fire phenomena available for experimentation. A change in direction in 1986 led to its subsequent development as a prototype of a well-structured model. In 1989, it was decided that developing many computer programs was inefficient. Two new programs resulted: CFAST and FPETool.

CFAST is intended to operate on many platforms. It is as error-free as is humanly possible, it is simple to run for simple problems, and, at the same time, it can handle complexity. The code is also extremely fast. It is faster than any code of comparable completeness and complexity. It works on laptop personal computers, Unix workstations, and supercomputers. It provides for extensive graphics analysis with pre- and post-processing modules. It is extremely fast on single compartment cases, and the data editor allows tremendous flexibility for parameter studies, "what if" testing, and so on. It is intended to be a complete, yet very fast, computer code for calculating the effects of fire on the building environment. It is particularly well-suited to parameter studies of changes, both subtle and large, within a single compartment.

The phenomena that were developed over the past couple of years contributed to the development of HAZARD 2.0. Continuing in the tradition of providing a state-of-the-art hazard-analysis tool to fire protection professionals, these developments include new phenomena and features that fall into four areas: fire model, egress and tenability models, databases, and user interface and documentation.

The FPETool project was carried through as a basic DOS-based text package. Then a paradigm shift in the fall of 1995 led to a decision to improve the user interface, and the "fire simulator" fire model was replaced by an interactive version of CFAST. The new user interface, a graphical user interface, or GUI, was developed to improve the ease-of-use of this and subsequent fire modeling tools. This interface, called FASTLite, is the prototype for future versions of CEdit and HAZARD. FASTLite is a more robust and complete fire model than FPETool, and it incorporates enhanced versions of the FireForm modules, as well.

Overview of Recent Changes to the Software

The most obvious change in the HAZARD package is that most of the programs have been converted to extended memory. This has several implications for users. The first is that a 386/486/P5 processor is required, and a minimum memory configuration of 4MB is needed. This has allowed an increase to 15 in the number of interior compartments.

There are a number of additional phenomena that have been added, based on this increased capability. For example, a ceiling jet algorithm[2] has been implemented that takes into account heat loss from a fire placed in an arbitrary position within a compartment. The algorithm accounts for the fire's off-center placement and its effect on heat transfer to the room's surfaces. Implementation of this algorithm demonstrates the importance of detector siting in early detection. Smoke and heat detectors are being planned for the model so that studies can be conducted in a systematic manner for detection within compartments and for remote detection—that is, for detector siting in adjacent compartments. At present, the fire's location must be specified.

The next phenomenon to be included will be a pyrolysis and flame spread algorithm to allow for proper treatment of wall linings, mattresses, and cable trays. In order to implement such an algorithm, the radiation model had to be improved. It is now a ten-wall model for the four upper wall segments, four lower wall segments, ceiling, and floor. Numerically, it is simplified to four segments, based on symmetry of the rectangular parallelepiped used in our zone model.[3] It is just slightly slower than the earlier extended ceiling algorithm, but the improvement in accuracy is significant.[4]

The Exitt (sic) and Tenab modules have been combined into a single entity called Survival. The salient difference Survival offers is that incapacitation or death will prevent a person from moving. The original thrust of Exitt and Tenab, which allows the user to see relative effects of toxic insults, will be incorporated into Survival. When this is accomplished, we will no longer include the Exitt and Tenab modules in the HAZARD package.

Phenomena That Are Now Incorporated into the Fire Model

- Multiple compartments (currently 15, proposed 30),
- Multiple fires—specify with "other" objects,
- Vitiated or free burn chemistry in the lower layer, the upper layer, or in the vent flow,
- Consistent production and transport of species,
- Simple flame spread (vertical and lateral),
- Four-wall and two-layer radiation,
- Four-wall conductive heat transfer through multilayered walls, ceilings, and floors in each compartment,
- Conductive heat transfer through barriers (ceiling/floor conduction),
- Convective and radiative heat transfer applied both to inside and outside boundaries,
- Wind effects—ASHRAE formula for wind with the NOAA integral for lapse rate of the standard atmosphere,
- Fire plume and entrainment in vent flow (doors and windows only): Fire plume is split into the entrainment in the lower layer and the upper layer,
- Three-dimensional specification of the location of the fire and nonuniform heat loss through boundaries,
- Generalized vent flow, which includes
  - –Horizontal flow (doors, windows and so on)—up to three neutral planes,
  - –Mixing between the upper and lower layers,
  - –Vertical flow (through holes in ceilings and floors), and
  - –Mechanical ventilation
- Separate internal and external ambient (elevation, temperature and pressure specification),
- HCL deposition,
- Detection—smoke or heat, and
- Suppression—0th order by water (no geometry effects).

While the usefulness of some aspects of the data input structure may not be apparent, it is important to present information and choices that people who use the tools will understand. So, for example, while it is possible to use an effective kρC for arbitrary wall structures, those who design and build structures think in terms of the components.

Egress and Tenability Model

The project to develop a quantitative hazard assessment method was initiated following the NBS Workshop of Combustion Product Toxicology held in 1982.[5] In this workshop, papers that covered some of the initial concepts of hazard analysis were presented. The general approach for the hazard analysis capability was discussed in the *Journal of Fire Science* early in 1983.[6] Later that year, NBS made a commitment to produce a practical hazard assessment method in 3–5 years.[7] HAZARD I and the accompanying software and documentation is a prototype of this method.[8,9,10]

EXITT models the evacuation of building occupants exposed to a growing fire. It is a deterministic model that uses the layer height and smoke density data from CFAST, along with a set of behavioral rules, to predict the actions of each occupant. Based on an occupant's action, the program determines the occupant's destination. It then determines the shortest "safe" route to arrive at the destination. When an action is completed, the occupant is assigned a new action, and the process is repeated. The program ends when all occupants are either out of the building, or unable to act.

TENAB estimates the hazard, as determined by a set of tenability measures, to which each occupant is exposed as he or she performs designated actions. TENAB uses the occupant time and location data from EXITT, along with the environmental data from CFAST, to determine the tenability conditions for each occupant or compartment. When a measure exceeds a certain level, the occupant is considered incapacitated or dead.

Limitations

These phenomena can be improved:

• *General*—Pyrolysis (and flame spread) models still depend on test methods. No heating/cooling in HVAC ducts or reverse flow in fans is allowed.

• *Entrainment*—Fire plume and doorway jet entrainment are based on the same experimental correlations. The fire plume (for large spaces) and the doorway jet (in general) are often used outside the normal range of validity for these correlations.

• *User specification*—The level of agreement is critically dependent on careful choice of the input data for the model. A better understanding of typical fire-induced leakage in buildings would facilitate a more accurate description of the building environment.

• *Statistical treatment of the data*—Presentation of the differences between model predictions and experimental data are intentionally simple. With a significant base of data to study, appropriate statistical techniques to provide a true measure of the "goodness of fit" should be investigated.

• *Experimental measurements*—Measurement of leakage rates, room pressure, or profiles of gas concentration are atypical in experimental data. These measurements are critical in assessing the accuracy of the underlying physics of the models, or of the model's ability to predict toxic gas hazard.

Overview of Future Improvements

The Hazard methodology will be improved by:

• Increasing the number and improving the capability of the phenomena are modeled

- Improving the usability of the package
- Providing derivative applications
- Expanding the methodology's scope

As the concept of fire safe structures takes hold, several questions will arise. How much will improvements cost, how much will they save, and what will be the likely actions of those involved in a fire? One area we have not discussed explicitly is the valuation of a building or system subject to a fire, and what the worst, or most probable, fire and concomitant dollar loss would be. Such a capability will be developed, as will that for estimating the physical effects of a fire.

HAZARD is now published with some sample cases, but by providing a set of cases from start to finish with a data file and a video of an actual fire scenario, program usage would increase. We could include a presentation of a fire and its consequences. This might include computer-formatted video and concomitant data sets for simulation.

The concept of general building/people/fire interactions should also be included. Three aspects could be addressed. The first is the people/building interaction. The second is an integrated model for commercial, industrial, and residential rules. The third is an editor for people-movement rules. The fire model is sufficiently fast that the run time for graphics is almost irrelevant. It should be possible to develop Survival so that the people interact with the fire by having Survival call the CFAST kernel.

The front-end graphical user interface (GUI) for CFAST/HAZARD v2.0 should be an improvement over the text-based interface we currently use. The intent is to extend this to all aspects of modeling, including the use of the FireForm idea as a utility within HAZARD. The GUI concept was first embodied in FASTLite and the CFAST shell. In the future, FASTLite will contain a simple, single-file editing session. The long-range plan is to allow editing of multiple sessions while the model is running. In some ways, this goes beyond our original goal of providing a simple filter to prevent egregious errors, but it will allow us to make the databases much more versatile without encumbering users. We will extend the editor to include the graphics output, as well as people placement and specification of those aspects that affect peoples' behavior. The new GUIs will present a graphical, two-dimensional representation of a building. Also under development are computer-aided-design (CAD)-based input and output displays. These improvements should encourage use of these models by architecture firms and others who aren't conversant about fire problems, but who are intimately concerned with buildings.

An important extension of the Hazard methodology is the concept of automated parameter variation, which includes incorporating the probability of actual events to ascertain the relative effect of particular scenarios. This capability will increase the usefulness of our models manyfold. As part of this work, we will develop a mechanism to determine the sensitivity of the outcome to the parameters themselves (fine variation) as well as their variation (gross variation). A critical point will be to decide on a reasonable extent of variation. For example, if we consider a door that will be open or closed, should we consider it to be absolutely closed or fully opened, with leakage from a crack of ⅛", ¼", or ½" and fully opened, or with some other combination of factors?

New Phenomena Needed for the Fire Model

We need to incorporate many new phenomena. Those under active consideration include:

- Compartment-to-compartment heat transfer via heat conduction,
- Flow within compartments,
- Burning at corners (furniture, adjoining walls),
- Structural effects (barriers to smoke and fire spread, as well as load-bearing capability),
- An improved pyrolysis model (based on more fundamental physical aspects of materials),
- Construction design files (databases used for building and ship design),
- Self consistent fire—both a flame spread model and a pyrolysis model,
- An improved understanding of species generation, such as CO/CO_2, and its source,
- Two-directional heat transfer in walls (noncongruent thermocline),
- Better detector and other sensor activation (including new detectors),
- Deposition and agglomeration of smoke and other species,
- Suppression—include fire size, drop size and distance effects, geometry of the fire, evaporation/cooling,
- Modifications to all modules to utilize Fire Date Management System (FDMS),[11,12] databases,
- Corrosion—add on for HCl (important in the semiconductor industry and warehouses), and
- Smoke movement in tall shafts, stairways and atria.

Databases

An important part of our work is providing various types of databases so that companies will be able to make decisions on products or building assemblies. We are redoing the FDMS concept for two reasons: First, it is very difficult right now to add new types of tables. This has resulted in many people abandoning the system. Second, for fire modeling work, a consistent and well-defined database structure is needed for validation data, the various data sets used within the models, and so on. We are developing the new structure and modules with the caveat in mind that previous work should fit into the new model and be usable. We now deliver HAZARD with some sample cases. It would be beneficial to those unfamiliar with this tool to be able to run through a set of test cases from start to finish on a video showing the actual fire test. Perhaps if we begin to develop this now with cooperation from those doing full-scale tests, we could show fire and its consequences in computer-formatted video, along with concomitant data sets for simulation.

New Technology

Technologies that should be addressed and embraced include the diversity of evolving computer platforms, networks and multiprocessor systems, and new hardware such as CD-ROM. CD-ROM technology will allow us to include the necessary databases for compatibility with the new generation of fire models. In addition, we can include video sequences of some of the sample and test cases. Now, we need to run actual fires of some of the sample files we distribute with HAZARD and include the video with the distribution.

Currently, there are more than 100 million microcomputers in use, and this number, which includes high-end workstations, is likely to continue to increase. Manufacturers are beginning to develop small-scale parallel systems, and the cost of adding a processor board is only about 20% of the cost of a new system. The implication is that 2 to 10 processor systems are likely to become the norm for computer systems. Also, office systems are being networked, especially for people with both homogeneous and heterogeneous systems. We should be able to take advantage of these hardware configurations. This will become more important as the models become more complex and computer time increases. We are beginning to develop a method to utilize this parallelism.

Capabilities and Processing Power

For real-time firefighting, a portable, hand-held computer could be developed to allows the user to walk through a building before or after a fire and catalog the contents. This device could be brought back to the office and used directly as input to the model for geometric specification and data initialization. As the Cellular Digital Packet Data becomes more prevalent, on-site inspections will allow such hand-held computers to interact directly with desk-bound servers for maintaining databases and ascertaining code compliance. As the model becomes more sophisticated and its complexity increases, researchers, code officials, and others will come to depend on such stratagems. There simply is not enough time to fuss with all of the details. This is the arena which should allow us to pursue the goal of a better qualitative understanding of fires, as well as doing more of it faster.

All large buildings have annunciator panels for various alarms. Indeed, some fire departments can display floor plans of buildings in the fire command center. It is a logical next step to plug these displays into the alarm system to see the current status of a building and then predict what will happen over the next five minutes. At present, there is not sufficient information available at these sites to implement such a concept, but as buildings become "smarter" and sensor rich, such a path will seem natural.

Extension to Risk Assessment

Another area for expansion is that of risk. Risk is the next step up from a hazard calculation and requires a much more general understanding of the parameters that affect the outcome of a fire and its impact on people and structures. This application would require an automated application of the model over types of fires, day and night scenarios, the fire's position, and so on. Such calculations multiply to such an extent that some means of calculating these variables in a finite time will need to be found. Also, in order to provide performance evaluation tools, it is necessary to know how often a scenario does not happen, as well as what to do when a catastrophe occurs. An important aspect of developing a risk tool will be a means to winnow down the number of calculations that must be performed in order to complete a study quickly enough to be valuable.

As we extend the capability of the zone models, we encounter their inherent limitations. A zone model, or control-volume model, uses volume as one of the variables. Inherently, no spatial information is available. However, height versus width information is necessarily included to calculate flow through a normal vent, such as a door, as well as flow through a ceiling/floor opening and through mechanical ventilation. We have already extended the zone model concept to accommodate the position of the fire. We must now take one more step and define the spatial component of a compartment.

Usability

The automatic transfer of information from one set of calculations to another is important to avoid unnecessary errors and repetitive data entry. Our goal is to provide a mechanism that allows researchers, fire protection engineers, code officials, and so on to access the most current research results on fire behavior. To reach this goal, we try to improve the physical basis of the model. At the same time, we hope to allow more extensive calculations for long corridors, three-dimensional effects, and so on, and these issues hinge on faster computers, distributed processing, automatic data transfer, and a more intuitive interface. Finally, we have to calculate the human factors to determine how much fires really cost. Since our knowledge of a situation is not perfect, we must ask what range of results we might expect, given a most likely scenario.

Input from those who use such tools is crucial to identifying the most needed changes. Through this process, research priorities can be established to address the needs of the community in the most efficient manner. In addition, we invite the research community to review and comment on this effort. The gaps in knowledge identified here can then help resolve the issues we face. The obvious conclusion is that our understanding of fire is imperfect. As we continue to plumb the depths of this problem, both the direction and scope of the methodology will be influenced by what users say is needed, as well as the results of the center's own research.

Improvement in Egress and Tenability Modeling

These two programs are being improved in four areas: consolidation, data input, data display, and expansion. Since these two models rely on an existing body of research results, only through changes in our understanding of human behavior and survival in a environment loaded with combustibles can we alter these models in a meaningful way. The major activities that make up this task are:

- consolidation of the egress and tenability models - this has been accomplished,
- consolidation of the input structure of this combined model with the fire model,
- development of a "rule processing engine" for the egress model to allow the program to respond to different sets of rules for human behavior,
- enhancement of the input and output displays of the program,
- development of rules for the new "rule processing engine" based on the current set of egress rules in EXITT and (depending on the availability of research on people movement in larger buildings) on egress rules for larger occupancies, and
- development of rules for the new "rule processing engine" based on the current tenability rules.

Interactive Egress Modeling

The ways in which people and buildings interact with fire constitute the most intriguing of the concepts covered here. There are three ways in which we might address these interactions. The first is to examine the interaction of people and buildings. The second is to develop an integrated model for high-rises and residential dwellings. And the third is to create an editor to generalize about how people move during a fire. The fire model is sufficiently fast that the run time graphics are not as useful as they were in previous releases. It is generally easier to rerun the animation program to generate the original output than to look at it while the model is running. Thus, it should be possible to develop SURVIVAL so that the people interact with the fire by having SURVIVAL call the CFAST kernel.

The Next Version of The Fire Hazard Assessment Methodology

The focus on extending this methodology is to develop a more holistic approach to buildings, as well as a more complete set of phenomena. That is, one must take the structure of the building into account. This arises in the form of intercompartment heat transfer— two-dimensional heat transfer through walls, vertically as well as horizontally—so that when several rooms are connected to a corridor, the correct heat flux into the corridor is calculated. Also, the movement of smoke down a long corridor is of interest to many. Thus, we are faced with placing compartments together and having the computer figure out what to do with them.

Incorporating a New Phenomenon

Including a new feature into any model is rarely a trivial process. Even with a modular algorithm design, significant time is required to "insert" the new phenomena following these steps.

• First, its is necessary to study the algorithm and its associated documentation in enough detail to understand how it affects the entire model's environment. This will allow the modeler to manipulate the module's input and output variables to allow the model to communicate with the module. Also, we must ascertain whether the required data is generally available through database and literature searches.

• Next, we must adapt the algorithm's coding—assuming it has been coded—to the model. This may involve changing variable names or calling sequences to be consistent with the rest of the model, adding input for data required by the module, or adding appropriate output to present the results of the module's calculations.

• Testing and verifying the correct functioning of the algorithm is the next step. This will typically involve numerous model runs to compare with earlier results and to test the "new model" over a range of conditions. Limits of applicability, appropriate comments when these limits are exceeded, and suitable action or limiting results in these cases must be determined.

• At this point, we must adapt—or develop from scratch—appropriate module documentation to be included in the documentation for the entire method. This involves both an editorial function, to ensure consistent readability of the entire model's documentation, and extending the set of the model's examples to demonstrate a new feature. As part of the process of integrating a new phenomenon, a rationale, data availability, and output interpretation must be developed.

• Finally, we must examine and modify the internal structure of the model to address any new quantities that the module might predict. This may include modifying additional modules that can now be made more correct or efficient as a result of the added module. In addition, the supporting software may need to be changed to address additional input and output associated with the new module.

There are three levels of incorporating new features that must be addressed. In the concept of small, medium, and big (or very big), we essentially address the issue of how much work needs to be done, starting from the concept that we wish to include. For example, adapting an algorithm from a research paper is not straightforward. There are implications for the range of validity, as well as usefulness. Also, we must concern ourselves with the smoothness of correlations. An example of such a problem that we recently addressed is that of plume flow. We used the correlation developed by McCaffrey,[13] who divided the plume into three regions, depending on how much combustion occurs in each region. As it turns out, there were discontinuities at the transition points. In some cases, this would cause the solver (numerical integrator) to slow down dramatically. Further, since the phenomena must be continuous in real life, McCaffrey's correlations were *prima fascia* incorrect. The change to fix this was minor, but it illustrates some of the difficulties inherent in making the transition from research to practice.

A somewhat surprising finding from our research is that architects have little interest in the three-dimensional aspects of buildings. The actual fitting that must take place seems always to be placed on the construction end. This observation has shaped the vision of HAZARD to consider the three-dimensional effects of buildings, yet keep the interface simple.

Along the lines of keeping the paradigm simple, there is a need for quick estimates based on realistic scenarios. That was one of the appeals of the early version of FAST.[14] It was simple to use, and it gave reasonable answers, quickly. We have evolved to a much more complex world, but sometimes the simple answers are sufficient. The appeal of FireForm is that it is simple to use. In this case, however, it is too simplistic, and often it is not supportable because it has to be tweaked for each nuance of the physical model. As long as there is someone dedicated to doing this, it will continue to grow. However, like the Harvard code, it is too much of an insider's tool for new people to pick up. However, the need for this function still exists, and the concept is valid. We attempted to incorporate such estimates into the data editor (CEdit). We could never seem "to get around to it," so nothing came of the effort. The HAZARD shell includes the calculational procedures from FireForm.

We will begin to pursue some of these goals next year. We plan to improve the numerics and the way conduction is handled. This will allow us to incorporate a more extensive two-dimensional formulation in a timely way. Also, we are being asked to look at intercompartmental heat transfer. Although we are likely only to be able to do ceiling/floor transfer, we should have a better idea of the physical problem involved in doing more.

It should be possible to extend the GUI concept to all aspects of user interaction, including the use of FIREFORM as a utility within HAZARD. Our concept of a GUI was embodied first in FASTLite, CEDIT, and the HAZARD shell. In the first installation, we will have a simple single-file editing session. The long-range plan is to allow editing of multiple sessions and concurrent execution of the model. In some ways, this goes beyond our original goal of providing a simple filter to prevent mistakes. But it will allow us to make the databases much more versatile without encumbering the user too much. We will extend the editor to include the graphics output as well as the people placement and specification of those items that affect people's behavior. This thrust is important to allow general use by the building community.

Parameter Variation and Estimation of Probabilities

One of the most important extensions of HAZARD I is the concept of automated parameter variation, which includes incorporating the probability of actual events to ascertain the relative effect of particular scenarios. This capability will increase the usefulness of our models manyfold. As part of this work, we will develop a mechanism to ascertain the sensitivity of the outcome to the parameters themselves (fine variation) as well as their variation (gross variation). A critical point will be to decide on a reasonable extent of variation. For example, if we consider a door that will be open or closed, should we consider it to be absolutely closed, with leakage, cracked open ⅛". ¼," or ½" and fully open, or some other combination? Those ranges and combinations are under consideration.

Conclusions

The goal is to provide a tool which will help improve the understanding of fires and fire prevention. This is not an attempt to make the application of models trivial, but rather to provide a mechanism to allow researchers, fire protection engineers, and others access to the most current research on fire behavior. Improving the physical basis of the model is the means to reach this goal. At the same time, it is hoped that it would be possible to allow more extensive calculations, such as long corridors, three dimensional effects, and the use of faster computers, distributed processing, and automatic data transfer. Although the concept of a more intuitive interface is a valid goal, there really is no such thing as an intuitive user interface. Our goal is to provide a tool that helps and and does not hinder the understanding of fire effects and phenomena.

The goal of developing a building performance evaluation tool requires a concerted effort from many organizations. NIST could:

• Develop a framework for expressing and analyzing fire safety performance requirements for buildings as a nationally accepted alternate to the current requirements, using CFAST/HAZARD 2.0 and FASTLite.

• Develop a prototype computer-aided design system for fire hazard models that will allow architects and engineers to evaluate innovative building designs and new material applications against fire safety performance criteria. This system will allow analysis of design variations for reducing construction costs while increasing the level of safety. As part of this effort, we might explore using online data (CD-ROM and Internet), initiate a consortium to draft a performance standard, and develop a model verification methodology.

• Conduct a demonstration project with local code authorities (AHJs) on the process and advantages of the design and analysis system. This would constitute a prototype of a performance evaluation system and explicate the tool selection methodology.

• Deliver a method for estimating design safety factors and provide guidance for establishing acceptable levels of fire risk based on societal risk decisions and a metric for the cost/benefit of various implementations. Trial implementation with model codes and start-to-finish project analysis are part of this process.

• Demonstrate a methodology to examine performance-based codes, which will result in a draft of performance-based methodology.

• Evaluate a performance methodology in the field.

This action plan would further the goal of the whole fire safety engineering community, but to achieve it, a concerted effort from standards organizations, engineering professional societies, and building officials, as well as NIST, will be necessary.

References

1. Bukowski, R. W., Peacock, R. D., Jones, W. W. and Forney, C. L., "Fire Hazard Assessment Method," *NIST Handbook 146,* Volumes I, II, and III, National Institute for Standards and Technology, Gaithersburgh, Maryland (1989).

2. Cooper, L. Y., *Fire-Plume Generated Ceiling Jet Characteristics and Convective Heat Transfer to Ceiling and Wall Surfaces in a Two-Layer Zone-Type Fire Environment: Uniform Temperature Ceiling and Walls,* National Institute of Standards and Technology Internal Report 4705 (1991).

3. Forney, G. P., Computing Radiative Heat Transfer Occurring in a Zone Fire Model, National Institute of Standards and Technology (USA) Internal Report 4709 (1992).

4. Hoover, J. H., *Validation of Gas Phase Absorbance Algorithm in the Consolidated Fire Growth and Smoke Transport Model (CFAST),* Naval Research Laboratory Letter Report 6180/0020A (1996).

5. Snell, J. E., Levin, B. C., and Fowell, A. J., Workshop on Combustion Product Toxicology, *Summary of Presentations,* September 10, 1982, U.S. National Bureau of Standards, NBSIR 82-2634 (1982).

6. Snell, J. E., "Hazard Assessment: Challenge to Fire Science," *Journal of Fire Science,* Volume 1, No. 4 (1983).

7. Lyons, J. W., Statement of Dr. John W. Lyons before the Senate Committee on Labor and Human Resources, Hearing on Fire Safety Issues, July 19, 1983.

8. Bukowski, R. B., Peacock, R. D., Jones, W. W. and Forney, C. L., "Technical Reference Guide for the HAZARD I Fire Hazard Assessment Method," *NIST Handbook 146,* Volume I, National Institute for Standards Technology, Gaithersburgh, Maryland (1989).

9. Bukowski, R. B., Peacock, R. D., Jones, W. W., and Forney, C. L., "Example

Cases for the HAZARD I Fire Hazard Assessment Method," *NIST Handbook 146,* Volume III, National Institute for Standards Technology, Gaithersburgh, Maryland (1989)

10. Jones, W. W. and Peacock, R. D., "Refinement and Experimental Verification of a Model for Fire Growth and Smoke Transport," paper presented at the Second Annual Symposium on Fire Safety Science, Tokyo, Japan (June 1988).

11. Portier, R., "A Programmer's Reference Guide to FDMS File Formats," NIST Internal Report 5162 (1993).

12. Portier, R., *Fire Data Management System, FDMS 2.0,* Technical Documentation, National Institute of Standards and Technology Technical Note 1407 (1994).

13. McCaffrey, B. J., "Momentum Implications for Buoyant Diffusion Flames," *Combustion Science and Technology,* Volume 52, Number 149 (1983).

14. Jones, W. W., "Refinement of a Model for Fire Growth and Smoke Transport," NIST Technical Note 1282, 1990.